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The cognitive representation of a throwing technique in judo experts – Technological ways for individual skill diagnostics in high-performance sports

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Objectives: The paper addresses the cognitive skill representation of a judo technique and presents two examples on how to measure and interpret individual skill profiles based on these representations in high-performance sports.
Method: The cognitive skill representation of a throwing technique in high-level judo experts was tested with the Structure Dimension Analysis - Motorics (SDA-M). This method provides psychometric data on the mental structure and feature dimensions of movement representations in long-term memory. The cognitive units of such representation structures are so-called basic action concepts (BACs), which correspond to functionally meaningful body postures and sub-movements. Participants performed a hierarchical distance scaling (splitting task), in which they sorted a list of BACs according to their functional relevance in movement execution. Through a hierarchical cluster analysis, the SDA-M uncovered the cognitive structures of the throwing technique in participant's long-term memory, and enabled the assessment of group and individual representations.
Results: Expert skill representations were organized in a distinctive hierarchical tree-like structure, which matched the functional and biomechanical demands of the task well. Also, insights about specific movement problems could be gained for two experts after assessing their individual structures.
Conclusions: The SDA-M method can be used as a diagnostic tool to measure individual skill representations, which helps to improve performance-related instructions and to optimize technical training routines in high-performance sports.

Knowledge representations about objects are stored in taxonomies of hierarchically organized memory structures, in which so-called basic object concepts fall into distinct categories (Hoffmann, 1986; Rosch, 1978; Rosch & Mervis, 1975). These knowledge representations provide the basis for the interaction with objects in everyday life (Hoffmann, 1990). Domain-specific knowledge representations in high-performance sports are organized in a similar way: Athletic expertise is signified by distinct memory structures, in which so-called basic action concepts (BACs) provide the representational basis for the voluntary control of complex actions (Bläsing, Tenenbaum, & Schack, 2009; Schack, 2004; Schack & Mechsner, 2006). This notion is in line with the tree-traversal model of the hierarchical control of movement sequences (e.g., Rosenbaum, Kenny, & Derr, 1983) and other early conceptions of movement representation (Restle, 1970). These theoretical frameworks describe the hierarchical control of movement sequences in terms of an inverted tree metaphor in a way that higher levels (nodes), which are thought to transmit movement information, branch into lower levels, where specific effector information is stored (see Povel & Collard, 1982). Importantly, with extended amounts of practice, associated control processes move from a higher, more abstract level to more specific, lower levels (cf. Jordan, 1995).

Schack and Mechsner (2006) investigated the cognitive representations of the tennis serve for high-level tennis experts, low-level players, and novices. In particular, they tested their participants' long-term memory structures for a specific number of BACs that could be associated to distinct phases of the movement skill (such as the pre-activation phase, strike phase, and the final swing). The results of their study revealed that in high-level experts, these representational frameworks were organized in a distinctive hierarchical tree-like structure, were remarkably similar between individuals, and were well-matched with the functional and biomechanical demands of the

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task. In comparison, action representations in low-level players and novices were organized less hierarchically, were more variable between persons, and were less well-matched with the task's functional and biomechanical demands. The authors concluded that such movement representations provide the basis for the voluntary control of skilled movements in the form of suitable organized perceptual-cognitive reference structures in long-term memory (Schack & Mechsner, 2006; cf. also Rosenbaum, 2010, p. 119–120).

Similar findings were presented in a recent study by Bläsing et al. (2009), who were able to demonstrate differences in the cognitive skill representations between novices, advanced and expert dancers for two complex ballet skills. A noticeable detail of their study was that advanced dancers showed some initial clustering, but were more variable in their structures than experts, while novices did not show any reliable representations of the two ballet skills. From this observation, it can be inferred that becoming an expert in a particular sport may also rely upon the development of cognitive skill representations.

These two previous studies (Bläsing et al., 2009; Schack & Mechsner, 2006) used the *Structure Dimensional Analysis – Motoric* (SDA-M; see Schack, in press, Hodges, Huys, & Starkes, 2007) to analyze cognitive skill representations across different levels of athletic expertise, particularly emphasizing differences between novices and experts in sports. The main goal of the present study is not to examine differences in the cognitive representation of sport skills between different levels of expertise, but to provide examples for the use of the SDA-M method on an individual level. While this has been already done in the field of clinical rehabilitation (Braun et al., 2007, 2008), there are no such examples within the domain of sport psychology. On one hand, this would provide for the opportunity to gain knowledge about an athlete's specific cognitive skill representation (i.e. his/her individual skill profile) and on the other hand, it would give coaches a tool to offer performance-related instructions and feedback, with the goal to optimize technical training beyond the use of traditional methods from biomechanics (i.e. analysis of movement kinematics), which most often rely on the expertise of judges and/or reference data for a particular movement. To this end, the present study investigated the cognitive skill representations of high-level judo experts to provide meaningful examples of how such practical knowledge can be gained.

Method

Participants

We tested 8 judo experts (6 male, mean age = 27.1 years, ranging from 21 to 32 years). Most all of the experts are current/or were previous members of the German National Judo Team and performed at the highest national and international level. Five experts participated at world championships and/or the Olympic Games and six are currently members of different 1st division judo teams. They had an average of 18.0 years of experience in the sport. All experts stated that Uchi-mata was among their preferred throwing techniques and that they used this technique in competition. They read and signed an informed consent form prior to the experiment. No financial benefit was provided for participation. The study was carried out according to the 1964 Declaration of Helsinki.

Skill Selection – the Uchi-mata throw in Judo

The skill under investigation was the Uchi-mata throw in judo, which is one of the most essential attack techniques performed in today's international judo competitions. Fig. 1 shows the sequence of actions during movement execution. Key-points within the

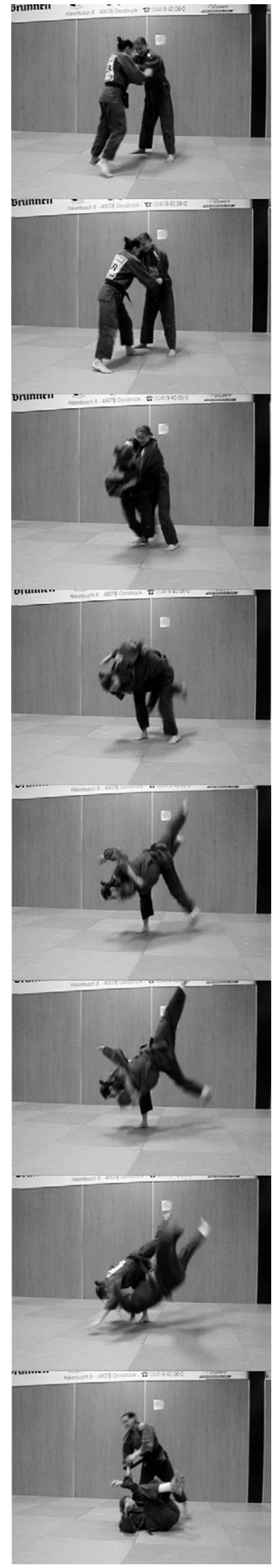

Fig. 1. The sequence of actions during the Uchi-mata throw in judo is presented. From top to bottom: Pictures 1–3 belong to the *pre-activation phase*, pictures 4–6 to the *main throwing phase*, and pictures 7–8 to the *final phase*.

functional structure of the throw were defined as Basic Action Concepts (BACs), according to procedures previously used in tennis (Schack & Mechsner, 2006) and ballet dancing (Bläsing et al., 2009). First, a preliminary number of BACs was selected after consulting movement descriptions form standard textbooks on Judo (Kano, 1994; Lehmann & Ulbricht, 2007; Robrecht & Fürnberg, 2004). Then, these BACs were judged and revised by four experienced judo experts (who did not take part in the study), before a set of fourteen primary key-points was finalized by the experimenters. From a biomechanical perspective, all BACs can be associated with a particular movement phase (main phase or auxiliary phases) during skill execution (cf. Göhner, 1992). For the present skill these are: BAC 1 (left arm pulls forward and upward), 2 (step-in right leg), 3 (right arm pulls collar upward), 4 (left leg follows with a step-in), 5 (left leg is bent and center of mass lowered), and 6 (contact with right hip and right upper body) belong to the pre-activation phase. BACs 7 (head and upper body rotate in throwing direction), 8 (left leg stretches and partner is being lifted), 9 (right leg lifts partner on the inside thigh), 10 (rotation of upper body forward and downward), and BAC 11 (stretch toes) belong to the *main throwing phase*. BACs 12 (bring upper body back upright), 13 (bring right leg back to a secure stand), and 14 (save and control partner) belong to the *final phase*.

In other words, the pre-activation phase deals with the preparation of the throw (i.e. breaking the opponent's balance and moving one's own body in for the throw), the *main throwing phase* with throw execution (i.e. rotating the opponent on his/her back), and the *final phase* with ending the throw (i.e. regaining balance and supporting the opponent's fall).

Task and procedures

Participant's cognitive skill representations of the Uchi-mata throw were measured using SDA-M (Schack, 2004, in press). It is assumed that the structure of movement representations can only be explicated to a limited degree and therefore, a splitting technique is used in which participants perform a distance scaling between the selected movement representation units (i.e. BACs). To this end, participants were sitting in front of a laptop computer and all BACs were repeatedly presented to the participants in randomized verbal lists. These lists had to be sorted according to a hierarchical splitting paradigm. Participants performed the splitting task by sorting the BACs presented on the screen according to their functional relevance to the first item in the list, which served as the current anchor. This anchor was always displayed in white font and highlighted by a red bar, while the active item was displayed in yellow font and the remaining concepts in black font. To guarantee that all perceptual features of the concepts are included in the decision process, participants were encouraged to perform or imagine (parts of) the movement skill. This was done to account for the inherent links between the motor and cognitive components of the concepts. All BACs, which were judged *"to be related to the anchor concept while performing the movement"*, were shifted to a related list on the left side of the screen, while BACs regarded as *"not related to the anchor while performing the movement"* were shifted to an unrelated list located on the right side of the screen. After splitting a current list into two sets (a related and an unrelated list), these two sets were displayed separately and participants could choose whether they wanted to accept or split them into further subsets. To finish the current list, participants were required to confirm this step by pressing a key, which activated the next list. The experiment was completed after confirmation of the last list. The decisions were non-speeded, all participants were tested individually in a separate room next to the training facilities, and the experimental procedures took 30–45 min.

Data analyses with SDA-M

Altogether, the SDA-M method consists of four steps: First, the splitting procedure involving the multiple sorting tasks described above delivers a distance scaling between the BACs of the predetermined set (i.e. verbal lists). Second, a hierarchical cluster analysis transforms each set of BACs into a hierarchical structure. Third, a factor analysis reveals the dimensions in this structured set of BACs, and fourth, the cluster solutions are tested for invariance within and between groups. (Psychometric details of the full procedure are provided by Schack, in press).

For the present study, only the first two steps are relevant and are addressed in more detail: The experimental procedure started by collecting information on the representational distance between selected BACs (Step 1). This was done by applying the previously described splitting technique in an experimental setting (see Task and Procedures), in which participants were asked to judge the functional relationship between two concepts. Each BAC was offered as an anchor (i.e. reference concept), to which the remaining thirteen BACs were either classified or de-classified according to an individually chosen similarity criterion. This procedure continued with the emerging (positive or negative) partial quantities (derived from the subset of the related and unrelated list) by retaining the reference concept (anchor) until an individual discontinuance criterion per participant was reached. By this procedure, fourteen decision trees were established, as each BAC appeared once in the anchor position. Subsequently, the algebraic sums of each branch of the decision tree (i.e. sums of the number of positive and/or negative decisions with regard to a particular reference concept) were determined on the partial quantities per decision tree, submitted to a Z-transformation for standardization, and finally combined into a Z-matrix. This matrix formed the starting point of all further analyses. Hence, the SDA-M method does not ask the subjects to give explicit statements regarding their representation structures, but rather reveals this structure by means of knowledge-based decisions in an experimental setting.

To measure the hierarchical structure of the representation in a second step, the Z-Matrix was transferred into a Euclidian distance matrix as basis for a hierarchic cluster analysis (in accordance with the average-linkage-method). This resulted in individual cluster solutions on the fourteen BACs formed as dendrograms. Each cluster solution was established by determining a critical Euclidian distance (d_{crit}), with all junctures lying below this value forming the apical pole of an underlying concept cluster. The steps three (dimensional analysis) and four (invariance measure) of the SDA-M were not performed, because we were not interested in between-group differences, but rather in examining the cluster solutions on an individual level. The use of the dimensional analysis and the invariance measure to detect differences between groups is further explained in Lander and Lange (1996) and Schack (in press).

Results

The dendrogram that resulted from the cluster analysis displays the average cognitive representation structure of the judo experts (see Fig. 2). The horizontal line on the right-hand side indicates the critical value $d_{crit} = 4.45$ for a significant alpha-level of $p = .0125$. The remoteness between a given pair of BACs is displayed in Euclidean distances on the right-hand side (with the critical value being $d_{crit} = 4.45$). From a statistical point of view, all BACs that form structures below this critical value are clustered together. From a memory-research point of view, the smaller a particular Euclidian distance value is for two BACs, the closer they are represented together in long-term memory (i.e. notion of concept clustering). It follows, that all BACs that are associated above the

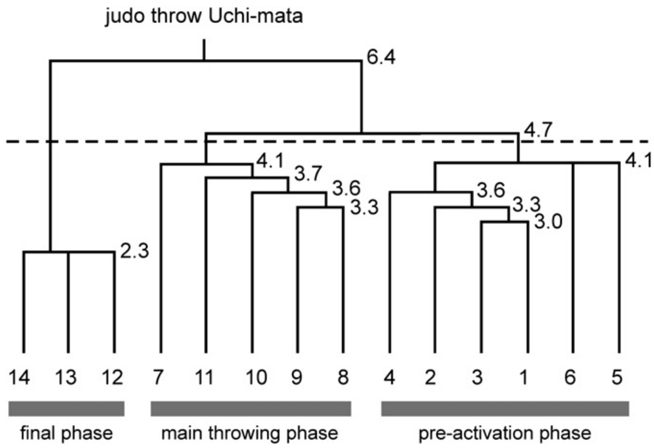

Fig. 2. Displayed are the average cluster solutions for the Uchi-mata of judo experts for all movement elements (BACs 1–14) in form of a dendrogram. The lower the numbers on the right-hand side, the lower the Euclidian distances between two or more BACs in long-term memory. The critical value was $d_{crit} = 4.45$ for an α-level of 1.25%. Pairs of BACs below this critical value are clustered together.

critical value are not clustered together and thus, are not represented in a single concept cluster. The analysis of the average group structure revealed the following cluster solutions: BACs 1–6 (pre-activation phase), BACs 7–11 (main throwing phase), and BACs 12–14 (final phase).

In an explorative *post-hoc*-analysis, we performed a more thorough diagnostics of the complex motor skill for two experts by examining the structure of their individual dendrograms. Participant 2 is a male judo player, competing in the 73 kg class, and his individual cluster solutions are displayed in the upper panel of Fig. 3. As can be seen, BAC 6 “contact with right hip and right upper body” is attached to the main throwing phase (and not to the pre-activation phase). Hence, the pre-activation phase (here BACs 1–5) is represented without the tight contact of hip and upper body with the opponent. Instead BAC 6 is clustered into the main throwing phase (here BACs 6–11). The final phase includes BACs 12–14, which are represented in closed association in long-term memory, as signified by small distance values in Euclidian space.

Participant 3 is a female judo player, fighting in the 48 kg class. As can be seen in the lower panel of Fig. 3, the pre-activation phase consists of BACs 1–6 (similar to the average experts’ dendrogram). Most interestingly, there are two further sub-clusters within the pre-activation phase. These sub-clusters correspond to the traditional separation of *Kuzushi* (breaking an opponent’s balance) and *Tsukuri* (moving one’s own body in for the throw) in classic Kodokan judo, which is the way how judo has been traditionally taught (cf. Kano, 1994). The main throwing phase then consists of BACs 7–10. Note here, that BAC 11 “stretch toes” is not included into this cluster, and therefore, singled out by the participant. The final phase combines BACs 12–14 and therefore, represents all elements, which are necessary to finish the throwing technique.

Discussion

The aim of the present study was twofold: First, the cognitive skill representations of judo experts were investigated for one of the most essential throwing techniques performed in today’s international judo competitions, the Uchi-mata throw. Second, two examples are presented on how to measure and interpret individual skill profiles based on cognitive representations in high-performance sports. These two objectives will be addressed in the remainder of the manuscript.

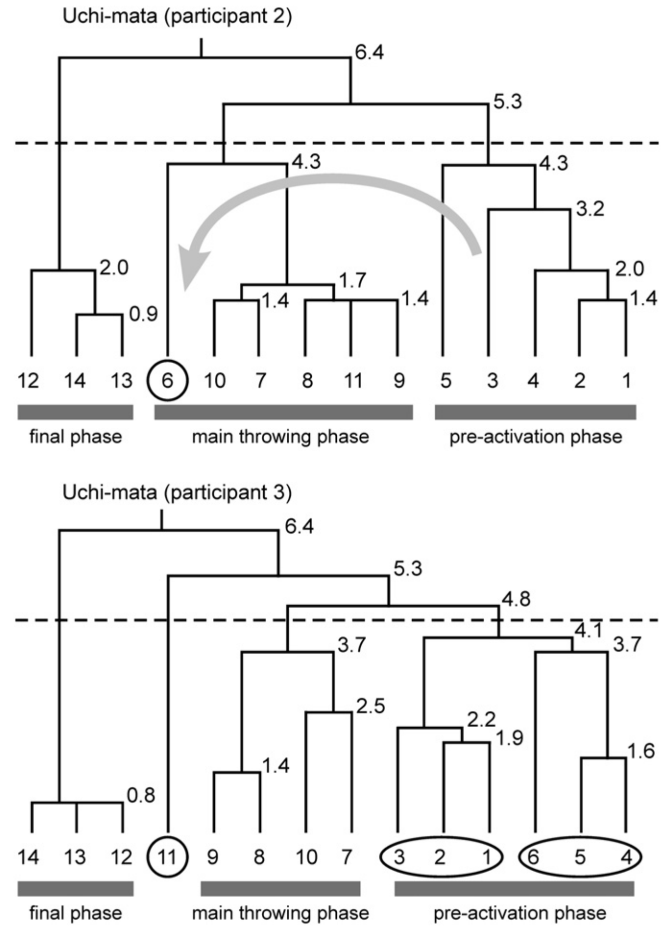

Fig. 3. Two individual expert skill representations are displayed. Upper panel: The long-term memory structure of Participant 2 reveals that BAC 6 (contact with right hip and right upper body) is not clustered within the preparation phase, but is attached to the main throwing phase. Lower panel: The BAC 11 “stretch toes” is not included into a cluster, and therefore, singled out by the Participant 3. Also, two distinct sub-clusters that correspond to the sub-tasks “breaking an opponent’s balance” (BACs 1–3) and “moving one’s own body in for the throw” (BACs 4–6) can be seen for the pre-activation phase.

The first objective concerns the general organization of cognitive representation structures in sport experts. In line with a number of previous studies on skill expertise, for example in ballet dance (Bläsing et al., 2009) and tennis (Schack & Mechsner, 2006), the high-level judo experts tested in the present study showed well-structured cognitive skill representations of the throwing technique (i.e. Uchi-mata). Their skill representations are organized in a distinctive hierarchical tree-like structure, are remarkably similar between individuals, and match the functional and biomechanical demands of the task. This similarity in the organization of cognitive structures is striking, given the differences between the sports under investigation in the present (Judo) and previous studies (ballet dance, tennis). For example, ballet dancers execute a continuous sequence of rhythmic skills during performance, which requires athletes to represent different positions and figures (e.g., *Pirouette en dehors*, *Pas assemblé*). Performers do not compete with each other on stage, but interact in a cooperative way, according to a specific playing script. Two tennis players compete with each other, but have no direct physical contact, and they use an implement to execute more discrete skills (e.g., serve, forehand). Judo players are in direct, physical contact with their opponent, use different techniques for their own attacks (e.g., Uchi-mata), but also have to react to their opponent’s attacks and

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counter-attacks throughout the fight. Given these obvious differences, it is remarkable how similar the cognitive structures of skill representation are between these sports, respectively. This similarity in the organization of cognitive structures hints to a more general principle of how movement knowledge is represented in human long-term memory (Schack, 2004, in press).

The second objective focuses on the SDA-M method as a diagnostic tool to examine cognitive skill representations on an individual basis to improve performance-related instructions and to optimize technical training routines in high-performance sports. For this purpose, subtle (meaningful) differences in the cognitive representations of two judo experts were identified to gain additional knowledge of the athlete's individual skill profiles of the throwing technique. Participant 2, a male player in the 73 kg class, included BAC 6 ("contact with right hip and right upper body") into the main throwing phase (Fig. 3, upper panel). Given further knowledge of the judo sport, this suggests that Participant 2 prefers the *koshi*-variation of the Uchi-mata. This variation (i.e. Koshi–uchi-mata) is being executed with a stronger hip involvement during the main throwing phase (as opposed to the *ashi*-variation, which is executed via a strong lifting movement of the right leg [i.e. Ashi–uchi-mata]). Certainly, the *koshi*-variation is a powerful technique in competition. However, lifting the partner with the right leg in this context might become important when the throw is being combined with another technique (such as during a deceptive action). In this case, the player must not bring himself too close to the partner (i.e. in the pre-activation phase), so that the hip and upper body are not in full contact with the opponent and any instructions must emphasize the lifting movement of the right leg, such as when combining the throw with a sacrifice technique (*Sutemi-waza*) in which the player proceeds onto a back-on-the-mat position during throw execution.

The sequence of action during the execution of the Uchi-mata throw is shown for Participant 3, a female player in the 48 kg class, in Fig. 1. As can be seen in pictures 4–6 of the main throwing phase, the athlete does not stretch her toes during throw execution. Most strikingly, this corresponds to what can be directly inferred from looking at the structure of her skill representation, in which BAC 11 "stretch toes" is not included into a particular cluster (Fig. 3, lower panel). The relevant instruction for Participant 3 to improve her throwing performance would be to *"focus on stretching your toes during throw execution"*. With regard to the biomechanics of judo throws, not stretching the toes can be problematic, because it results in a lower rotation point when the right leg and the upper body rotate around the hip during throw execution. This makes it more difficult to throw the opponent, especially when she/he actively tries to resist the attack. Throwing becomes easier, however, when the rotation point is higher and the opponent's stand is destabilized, because it is only supported by low ground friction forces. In technical preparation, it would be best to combine the verbal instruction (i.e. *"focus on stretching your toes during throw execution"*) with an explanation of this biomechanical principle to support a most efficient clustering of BACs and thus, to optimize the skill representation of the throw.

Conclusions

The SDA-M method can be used as a diagnostic tool in sport psychology, complementing previous methods in expertise research (e.g., verbal self-report, subjective ratings, or sorting methods). This experimental approach provides objective psychometric data, which can be further analyzed with advanced statistical procedures. Hence, measuring the cognitive representations of complex skills with SDA-M offers an effective tool to gain further knowledge about an athlete's individual skill representation. Most importantly, such skill diagnostics can inform coaches (and athletes) about specific movement problems that are reflected in the athlete's long-term memory structures. This provides the opportunity to improve performance-related instructions and gives coaches an additional diagnostic tool to optimize technical training routines. The SDA-M method goes beyond the use of traditional assessments in biomechanics, such as measuring kinematic parameters of human motion (e.g., Zatsiorsky, 1998), by unrevealing the cognitive representation structures of complex motor behavior in long-term memory (see Rosenbaum, 2010). The present study, and in particular the use of the SDA-M method as a diagnostic tool to measure individual skill representations in sport, complements recent studies in clinical rehabilitation (Braun et al., 2007, 2008) and extends current conceptions and methodologies on expertise research in applied sport science (Hodges et al., 2007; Schack & Bar-Eli, 2007; Schack & Hackfort, 2007).

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